Quantitative estimation of effective dose using dose length product in CT head at University hospital.

Background: Effective dose is the whole-body equivalent dose of partial body radiation exposure received during a radiological examination involving ionizing radiation. The aim of this study was to estimate the effective dose of radiation exposure in CT head scans, thus establishing a more comprehensive understanding of the potential health risks associated with CT head scans and providing a guideline to minimize those radiation induced risks during a Head CT.

Objectives: To estimate the effective dose in CT head scans among the patients attending CT head scans visiting the Department of Radiology, Dhulikhel Hospital; a University hospital

Methods: A retrospective, quantitative and cross-sectional study was conducted to study the effective dose in CT Head among 150 patients, age between 18 to 80 years requested for CT head examination at Department of Radiology, Dhulikhel Hospital (Kavre-Nepal) using 128 multi-slice SEIMEINS SOMATOM-perspective CT. Patient data regarding clinical history, investigation types, socio-demographic variables and lifestyle factors were collected by developing questionnaire. Also, data related to radiation exposure parameters (kVp, mAs, CTDIvolume, and Dose Length Product) were recorded for each patient displayed on the console of the CT scanner. The effective dose was calculated using DLP and conversion factor (k) for CT head. The estimated result weregraphically analyzed using multivariable linear regression analysis and correlated with different study variablesfor each CT Head examination.

Results: Out of the total 150 respondents, the estimated mean DLP for the CT head was 1083.497±115.76 mGy-cm, and the mean mAs and CTDIvol were 209.22±19.50 mAs and 48.34±4.18 mGy, respectively. The result showed a mean effective dose of 2.27±0.24 mSv.

Conclusion: The calculated effective dose for CT head was slightly higher in this study as compared to ICRP standards and previous studies. This study helps to suggest to further optimization may be achievable, and our data's specificity may enable researchers to provide more helpful recommendations than in the past. The survey's findings may spur additional

research on radiation exposure in other healthcare settings and aid in the establishment of national diagnostic reference standards.

Keywords: Computed Tomography, Dose Length Product, Effective dose, Radiation, Exposure

1. Introduction:

Computed Tomography (CT) scan has been widely used in medical imaging for diagnostic purposes.[1]Continuing advances in CT technology, such as the development of fast, helical scanning using multi-detector rows (MDCT),also known as multi-slice CT (MSCT), have promoted the increasing clinical application of CT and undoubted improvements in health care for populations.[2]Contemporary CT scanners facilitate the rapid imaging of large volumes of the patient and therefore promoting the development of new and complex diagnostic interventional procedures, with clear potential for further increases in the doses to individuals and populations.[3]The dose distribution inside the patient in CT is completely different from that for a conventional radiography. In conventional projection radiography, the dose decreases continuously from the entrance of the x-ray beam to its exit. In case of modern CT, due to its rotational geometry the dose is almost equally distributed in the scanning plane.[4]With an increasing radiation dose to the patients who underwent head computed tomography (CT) are significantly at higher risk of developing cataracts, and this risk may increase gradually with repeated CT Head examinations.[5] Since the eyes and thyroid glands are close to the area of interest during aCT head procedure, radiation exposure to these radiosensitive organs becomes a major concern. Various dose descriptors such as MSAD, CTDI, $CTDI_{FDA}$, $CTDI_{100,}$ $CTDI_{w}$, $CTDI_{vol}$, DLP and effective dose were used in CT for the assessment of potential radiation exposure to patients.[6] Effective dose can be considered as an important descriptor of radiation exposure of the patient. The next stage in this area of patient dose assessment is to address or estimate the risk of a CT examination and it requires the use of effective dose. Effective dose was originally developed by the International Commission on Radiological Protection (ICRP) as a risk-adjusted dosimetry quantity for the management of protection against stochastic effects, principally cancer, enabling comparison of planned or received doses with dose limits, dose constraints, and reference levels expressed in the same quantity.[7]Effective dose is used in radiation protection to relate exposure to risk, and it takes into account that different tissues have different radio-sensitivities and the absorbed dose to specific organs. Effective dose can be conveniently estimated by multiplying the conversion factors by the DLP values readily available from CT scanners.[8]

Effective dose (E) = k x DLP

Where the "k" coefficient is specific only to the anatomic region scanned; and Conversion factor for head =0.002.

2. Methods

2.1 Study design and Population

A quantitative, non-interventional, descriptive, cross-sectional study was among the patients who were referred for CT head scans visiting at of Radiology, Dhulikhel Hospital. Data were collected and analyzed to objectively measure and quantify the amount of radiation exposure delivered during CT head scans. Majority of the participants were found form Kavre district that underwent CT Head scan from September to December-2023 referred from various departments (e.g. Emergency, Neurosurgery, Medicine, Surgery, Orthopedic, ENT and Ophthalmology) and the emergency department of the Dhulikhel Hospital, who underwent CT head scans. All age group irrespective of age, sex and ethnicity who underwent CT head scans procedure were included. Patient's age ranging between 18 -80 years who providedthe consent for this study were included in this study. Also, patients with metallic jewelry and ornaments in the head and traumatic patients as well as severe hemodynamic instability and patient who require immediate medical intervention in case of patient from emergency department were excluded. Also, patients who had underwent multiple CT scan over time and those who refused to be participated in this study were also excluded in the study.

2.2 Sample Size

Sample size was estimated using the prevalence of effective dose from CT scanning using dose length product in a Nepalese hospital.[9]The prevalence of effective dose from CT scanning using

Dose Length Product (3%) was used in this based on previous literatures. With this, the initial sample size was estimated using the formula:

$$n = \frac{vZ^2\alpha_{/2}S^2}{d^2}$$

Sample size results to 84. Then considering and including all the margin of error, we planned to collect data of all male and female patients undergoing CT head in radiology department of Dhulikhel hospital during 4 months (September to December2023) i.e. 140patients.

2.3 Data Collection

Data were collected among patients underwent CT head scansat Department of Radiology, Dhulikhel Hospital. CT Head scan was performed using 128 multi-slice SEIMEINS SOMATOM-perspective CT systems and scan was obtained in helical axial plane from the level just above the occipital squamae to at the level of vertex. After the completion of scan, CT dose indicators were displayed at the operating console. Scanning parameters (kVp and mAs) as well as CT dose descriptors (CTDIvolume, andDose Length Product) was recorded and DLP was multiplied with the conversion factors (k) where Conversion factor for head =0.002.[8]

2.4 Statistical Analysis

The collected data were tabulated using MS Excel 2007 and STATA version 15(STATA Corporation, College Station, Texas 77845, USA. STATA 15) was used for statistical analysis. Descriptive statistical analysis was done by calculating frequencies and percentages for categorical variables while means and standard deviations were calculated for continuous variables. All the dependent variables like the socio demographic, life-style related and CT related factor were correlated using multivariable simple linear regression with calculated effective dose.In the multivariable simple linear regression models**Socio-demographic characteristics (**age, gender, body mass index, height, weight, marital status, occupation, religion and ethnicity, residency, Smoking, alcohol consumption) and CT related factors (peak-kilo voltage, milli-ampere second, computed tomography dose index and dose length product) were adjusted to identify the association with effective dose. Descriptive statistical analysis was performed by estimating frequency, percentage, mean, SD with graphical and tabular presentations. For inferential statistics, t-test was applied to find out significant differences between dependent and independent variables at 95% CI (confidence interval) where $p<=0.05$.

3. Results

Socio-demographic characteristics

Participants meeting the inclusion criteria were included in this study. Among them,57.1% respondents were found to be male and 42.9% were female. Also, 77.1% were found to be married and remaining 22.9% were unmarried. The mean age distribution of the respondents was found to be 45.6 years (±17.76) years. The respondent's minimum age was 18 years and maximum age of 80 years while the median age of the respondents was found to be 45 years. Similarly, the minimum height obtained was from 4.11 feet and maximum was about 6 feet with a median height of 5.3 feet (±0.34). Similarly, the mean body mass index was found to be 23.30, with a median of 23.3(± 3.17). Of the study respondents, majority 33.6% was employed. At all, 25.7% were smoker and also around 35.0% consumed harmful amounts of alcohol.

CT-related Factors

Throughout the study, the mean milliampere second was 209.2 (±19.50) in which minimum mAs130 mAs and a maximum of 251 mAs was obtained. Also the mean CTDIvol was found to be 48.34 mGy(±4.18) and mean DLP was 1083.497mGy-cm(±115.76).Similarly on the basis of Karl-Pearson coefficient correlation, correlation value of mAS, CTDIvol and DLP was found to be 0.74,0.79 and 0.99 respectively which shows they are found to be highly correlated with effective dose.

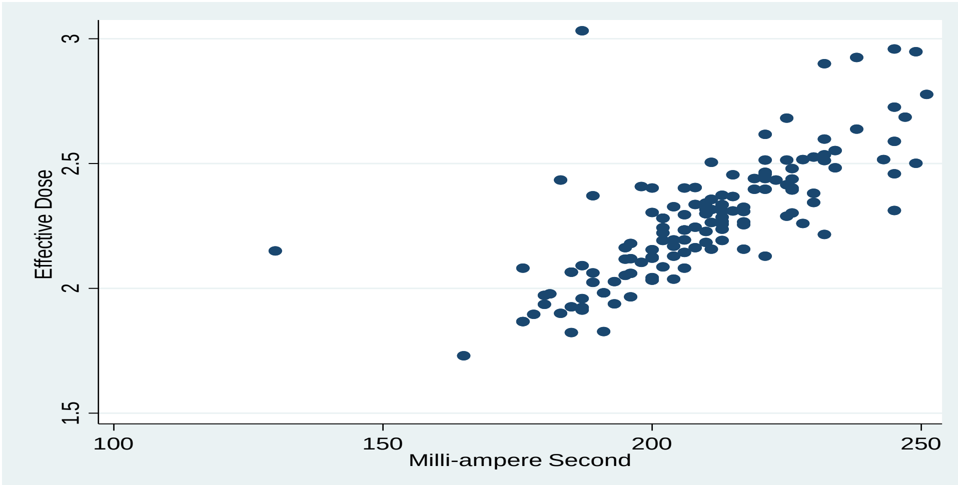

Fig 1: Correlation of mAs with effective dose

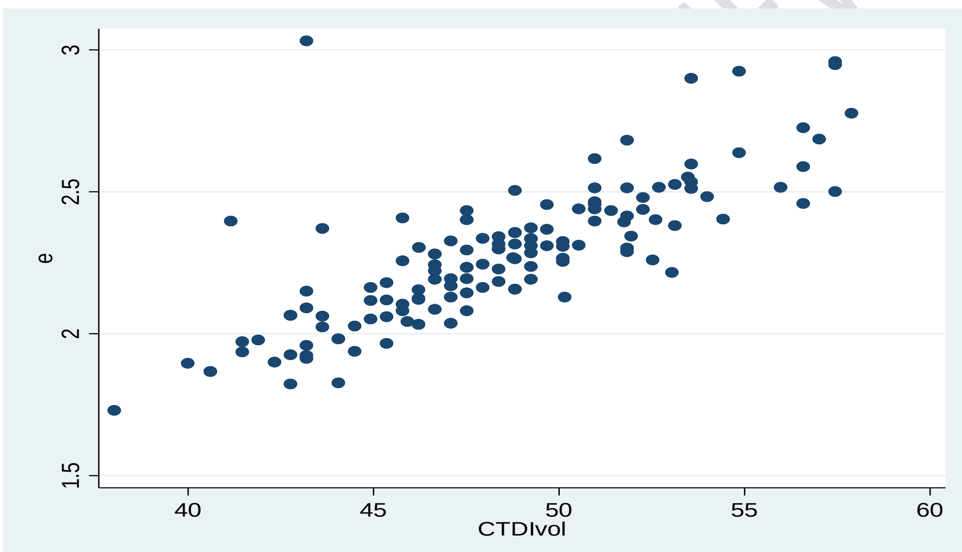

Fig 2 Correlation of CTDIvol with effective dose

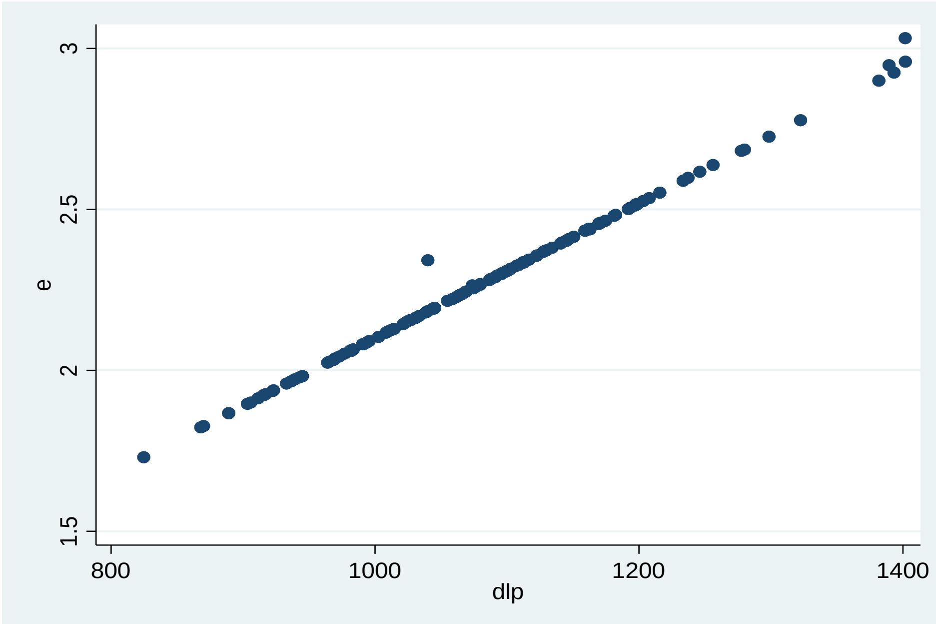

Figure 3 Correlation of dlp with effective dose

Table 1 Baseline characteristics presented with number and percentage (n = 140)

Characteristics	**Number**	**Percentage (%)**
Age of Participants(in years)		
Under 20	9	6.43
20-39	46	32.86
40-59	51	36.43
Above 60	34	24.29
Mean (±SD)	45.55, ±17.76	
Median (min: max)	45, (18:80)	
Gender		
Female	60	42.86
Male	80	57.14
Body Mass Index of		

Participants(kg/m^2)		
Below 18.5	3	2.14
18.5-24.9	96	68.57
25-31.4	41	29.29
Mean (±SD)	23.30 ± 3.17	
Median (min: max)	23.25, (17.2:30.6)	
Height of Participants(Ft)		
<5 feet	11	7.86
5-5.4 feet	72	51.43
>5.5	57	40.71
Mean (±SD)	5.31 ±0.34	
Median (min: max)	5.3, (4.11:6)	
Marital status of participants		
Unmarried	32	22.86
Married	108	77.14
Occupation of participants		
Housewife	27	19.29
Un-employed	35	25.00
Students	31	22.14
Employed	47	33.57
Place of residence of participants		
Kavre	140	100
Smoking status of participants		
No	104	74.29
Yes	36	25.71
Alcohol Consumption of Participants		

No	91	65.00
Yes	49	35.00
Peak Kilo-Voltage(kVp)		
130	140	100
Milli-Amperesecond(mAs)		
<176	2	1.43
176-199	36	25.71
200-223	69	49.29
>224	33	23.57
Mean (±SD)	209.22, ±19.50	
Median (min: max)	210, (130:251)	
Computed Tomography DoseIndex volume(CTDIvol)(mGy)		
<44	23	16.43
44-47	46	32.86
48-51	45	32.14
>52	26	18.57
Mean (±SD)	48.34, ±4.18	
Median (min: max);	48.37, (38.01:57.88)	
Dose Length Product(dlp)(mGy-cm)		
800-949	19	13.57
950-1100	63	45.00
>1101	58	41.43
Mean (±SD)	1083.497, ±115.76	
Median (min: max)	1083.265, (824.77:1401.89)	

The mean effective dose found was 2.27 mSv (95% CI: 2.23 to 2.31). The study revealed that the effective dose ranged from 1.73mSv to 3.032mSv, with a median of 2.28 mSv.

Table 2 Baseline characteristics of effective dose

Effective dose(mSv)	Mean (±SD)	Median (min: max) ;	95% CI
	2.27±0.24	2.28 (1.73:3.032)	2.23 - 2.31

Multivariable linear regression analysis was used to determine the association between socio-demographic and CT related factors with effective dose.The obtained mean difference for males in the adjusted model was 0.15 (95% CI: 0.07-0.23, *P*-value<0.001), and mean was 2.34 with a standard deviation of ±0.23.In the same way, respondents who were taller than 5 feet had a mean height of 2.32 and mean difference of 0.17(95% CI: 0.08-0.39, *P*-value = 0.009)with a standard deviation ± 0.24, which was higher than respondents who were taller than 5-5.4 feet, whose mean height was 2.26 and mean difference of 0.23 (95% CI: 0.02-0.33, *P*-value = 0.009) with a standard deviation ± 0.24.

Similarly, smokers' means were 2.32 and ±0.20, respectively, with a 95% confidence interval (CI) of -0.02-0.15 and a *p*-value of 0.167.The mean mAs above 224 was also higher than the mean mAs between 200-223 and 176-199, which had mean 2.27 with mean difference of 0.33 (95% CI: 0.08-0.58, *P*-value=0.001) and 2.05 with mean difference of 0.11(95% CI: -0.13-0.36, *P*-value=0.001), respectively. Additionally, the mean CTDIvol above 52 was 2.57mGy with mean difference 0.53 (95% CI: 0.43-0.63, *P*-value=0.001), which was higher than the mean CTDIvol between 48-51mGy and 44-47 mGy, which had mean difference of 0.30 and 0.12, respectively, with 95% CI 0.22-0.39 and 0.03-0.20 respectively. In a comparable way, the mean DLP above 1101mGy-cm was 2.50 with mean difference of 0.58(95% CI: 0.52-0.65, *P*-value=0.001) was greater than the mean DLP between 950-1100 mGy-cm with mean difference of 0.27(0.09, 95% CI: 0.20-0.33, *P*-value=0.001).The entire mean difference of effective dose between each category of factors based on simple linear regression was illustrated in table 3.

Table 3 Mean difference of effective dose between each category of factors based on simple linear regression (n=140)

Characteristics	number	Mean(SD)	Mean difference (Coef.)	95% CI	*P*-value
Age of Participants					
Under 20	9	2.20(±0.28)	Ref	Ref	
20-39	46	2.28(±0.21)	0.08	-0.96 - 0.25	0.684
40-59	51	2.29(±0.26)	0.09	-0.85 - 0.26	
Above 60	34	2.25(±0.24)	0.04	-0.13 - 0.22	
Gender					
Female	60	2.19(±0.23)	Ref	Ref	0.000
Male	80	2.34(±0.23)	0.15	0.07 - 0.23	
Body Mass Index of participants(Kg/m^2)					
Below 18.5	3	2.19(±0.28)	Ref	Ref	0.755
18.5-24.9	96	2.27(±0.23)	0.06	-0.18 - 0.31	
25-31.4	41	2.29(±0.26)	0.08	-0.16 - 0.34	
Height of participants(Ft)					
Below 5	11	2.08(±0.19)	Ref	Ref	0.009
5-5.4	72	2.26(±0.24)	0.17	0.02 - 0.33	
Above 5.5	57	2.32(±0.24)	0.23	0.08 - 0.39	
Marritial Status of Participants					
Unmarried	32	2.27 (±0.23)	Ref	Ref	0.879
Married	108	2.27 (±0.24)	0.00	-0.09- 0.10	
Occupation of Participants					
Housewife	27	2.23 (±0.27)	Ref	Ref	0.525

Un-employed	35	2.26 (±0.23)	0.03	-0.09 - 0.15	
Students	31	2.27 (±0.20)	0.03	-0.08 - 0.16	
Employed	47	2.31 (±0.26)	0.08	-0.03 - 0.20	
Place of Resident of Participants					
Kavre	140	2.27 (±0.24)	2.27	2.23 - 2.31	
Smoking Status of Participants					
No	140	2.25 (±0.25)	Ref	Ref	0.167
Yes	36	2.32 (±0.20)	0.06	-0.02 - 0.15	
Alcohol consumption of Participants					
No	91	2.26 (±0.26)	Ref	Ref	0.354
Yes	49	2.30 (±0.21)	0.04	-0.04 - 0.12	
Milli-Ampere Second(mAs)					
<176	2	1.94 (±0.29)	Ref	Ref	0.000
176-199	36	2.05 (±0.22)	0.11	-0.13 - 0.36	
200-223	69	2.27 (±0.12)	0.33	0.08 - 0.58	
>224	33	2.53 (±0.19)	0.59	0.34 - 0.85	
Computed Tomography Dose Index volume(CTDIvol)(mGy)					
<44					
44-47	23	2.03 (±0.26)	Ref	Ref	0.000
48-51	46	2.16 (±0.13)	0.12	0.03 - 0.20	
>52	45	2.34 (±0.11)	0.30	0.22 - 0.39	
	26	2.57 (±0.19)	0.53	0.43 - 0.63	
Dose Length Product(dlp)(mGy-cm)					
800-949	19	1.91 (±0.06)	Ref	Ref	0.000

950-1100	63	2.18 (±0.09)	0.27	0.20 - 0.33	
>1101	58	2.50 (±0.17)	0.58	0.52 - 0.65	

In this study, DLP had a substantial correlation (P<0.001) with outcome. The crude mean difference of 0.58 was 1.23 times higher than the adjusted mean difference of 0.47 (95% CI: 0.38-0.56) for DLP above 1101 mGy-cm. Similarly, the adjusted mean difference in DLP between 950-1100 mGy-cm was 1.12 times smaller than crude difference of 0.27, at 0.22 (95% CI: 0.15-0.33).DLP has significant impact on the effective dose based on the findings of the multiple linear regression models. Hence, in order to estimate the effective dose, the dose length product needs to be appropriately addressed. The entire mean difference of effective dose between each category of factors based on multiple linear regressions is illustrated in table 4.

Table 4 Mean difference of effective dose of each category of factors based on multiple linear regression (n=140)

Characteristics	number	Mean (SD)	Mean difference (Coef.) (crude)	Mean difference (Coef.) (adjusted)	95%CI	P-value
Dose length Product(dlp)(mGy-cm)						0.000
	19	1.91(±0.06)	Ref	Ref	Ref	
800-949	63	2.18(±0.09)	0.27	0.22	0.14 - 0.30	
950-1100	58	2.50(±0.17)	0.58	0.47	0.38 - 0.56	
Above 1101						

4. Discussion

The study showed a strong correlation between DLP and effective dose which reinforces the utility of DLP as a practical surrogate for estimating radiation risk in CT head imaging. The identified variations in effective dose among different scanners emphasize the need for standardized protocols and continuous quality assurance measures. The release of systematic estimates of organ and effective doses for various popular adult CT procedures in 1991, which resulted from a national survey done in UK, brought attention to the comparatively high patient doses associated with CT.[9] New and complex diagnostic and interventional procedures are being developed as a result of the ability of modern CT scanners to promptly image large patient volumes in a single rotation. This has the potential to further increase radiation doses to both individuals and populations.[10] Simultaneously, with the potential of dose reduction, more attention should be paid to maximize radiation safety through developments in CT practice and technology.[11]

In present study, computed effective doses was found to be 2.27±0.24mSv, while Z Brady et al.'s similar investigation demonstrated that the effective dose for head was 1.0-1.6 mSv.[12]The increase in dosage may have resulted from the increased milliampere-second (mAs) employed during the CT Head examination in our study. Similarly, Kharuzhyk et al. estimates the effective dosages for the head was found to be 1.4±0.4 mSv.[12].Moreover, a larger scan that avoided the topogram's field of view, or exceeding the limited the scan coverage, may have contributed to the increase in radiation dosage in our investigation. In addition to the various investigations, the study conducted by A. J. Van der Molen et al. demonstrated that the effective dose was higher than what we found. The study did find a noteworthy variation in the effective dose for head, which was 2.8 mSv.[13] These readings exceeded the 2.7mSv computed values in the study.

The larger scan area or higher irradiation volume may have had a significant role in the higher dose values observed, although the median CTDIvol values—which are used to calculate the DLP and, ultimately, the patient dose—appear to be lower than in the study by ErayAtl et al.[11]In addition, Nepalese individuals have smaller body habitus than people in European countries. Reducing the scan length as much as possible, without missing any vital anatomical regions essential for diagnosis, could be a first step for lowering DLP and subsequently the effective doses. In order to minimize the radiation exposure to the patient during CT examinations, it is crucial to reduce the milliampere-second (mAs) employed in the examination protocol in proportion to the patient's size.[14]

Furthermore, in clinical practice and in referral recommendations, the effective dose acquired for an adult patient may be utilized to estimate the population exposure dose, which would aid physicians in understanding the variances that occur throughout various examination approaches.[15]When planning and optimizing radiological protection, effective doses serve as a reference for the prospective dose assessment. They are also utilized to demonstrate regulatory compliance with dose restrictions. Therefore, for regulatory purposes, the effective dose is a central dose quantity for regulatory purposes.

5. Conclusion

This study provides valuable insights into the calculation of effective dose using DLP in CT head imaging. The findings of the study supports the use of DLP as a reliable parameter for estimating radiation risk, while also highlighting the importance of optimizing imaging protocols to ensure patient safety. The study revealed a higher dose level for head CT examinations. This greater dose could've resulted from not applying the two dose modulation techniques i.e. ATCM and ATVS. The higher milliampere-second (mAs) used during the CT scan in our investigation might have contributed to the dosage increase. Additionally, avoiding scan coverage limitations by increasing the scan could have resulted to a higher radiation exposure in our study. The diversity in CT effective dose suggests that there is still opportunity for optimization, and our data's specifics might render it feasible to provide more helpful suggestions than in the past.

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Conflicts of Interest

The authors have declared that no competing interest exists.

References

1. Lee C. How to estimate effective dose for CT patients. Eur Radiol. 2020 Apr 1;30(4):1825–7.
2. Shrimpton PC, Hillier MC, Lewis MA, Dunn M. National survey of doses from CT in the UK: 2003. Br J Radiol. 2006 Dec;79(948):968–80.
3. Prokop M. New challenges in MDCT. Eur Radiol. 15 Suppl 5.
4. Yu L, Liu X, Leng S, Kofler JM, Ramirez-Giraldo JC, Qu M, et al. Radiation dose reduction in computed tomography: techniques and future perspective. Imaging Med. 2009 Oct;1(1):65–84.
5. Alwasiah R, Jawhari A, Orri RA, Khafaji M, Al Bahiti S. Measurement of radiation dose to the eye lens in non-enhanced CT scans of the brain. Radiat Prot Dosimetry. 2021 Aug 14;195(1):56–60.
6. Dixon RL. The Physics of CT Dosimetry: CTDI and Beyond. Boca Raton: CRC Press; 2019. 232 p.
7. Harrison, J. D., Balonov, M., Bochud, F., Martin, C., Menzel, H. G., Ortiz-Lopez, P., ... & Wakeford, R. (2021). ICRP publication 147: use of dose quantities in radiological protection. Annals of the ICRP, 50(1), 9-82.
8. Christner JA, Kofler JM, McCollough CH. Estimating effective dose for CT using dose-length product compared with using organ doses: consequences of adopting International Commission on Radiological Protection publication 103 or dual-energy scanning. AJR Am J Roentgenol. 2010 Apr;194(4):881–9.
9. Vilar-Palop J, Vilar J, Hernández-Aguado I, González-Álvarez I, Lumbreras B. Updated effective doses in radiology. J Radiol Prot Off J Soc Radiol Prot. 36(4).
10. Yoon, W., Ryu, J. M., Lee, M. Y., Moon, Y. J., Lee, S. H., Park, J. H., ... & Han, H. J. (2010). 64-Channel multi-detector row CT angiographic evaluation of the micropigs for potential living donor lung transplantation. Journal of veterinary science, 11(3), 185.

11. Atlı E, Uyanık SA, Öğüşlü U, Çevik Cenkeri H, Yılmaz B, Gümüş B. Radiation doses from head, neck, chest and abdominal CT examinations: an institutional dose report. Diagn Interv Radiol. 27(1).

12. Brady Z, Ramanauskas F, Cain TM, Johnston PN. Assessment of paediatric CT dose indicators for the purpose of optimisation. Br J Radiol. 85.

13. Van der Molen AJ, Schilham A, Stoop P, Prokop M, Geleijns J. A national survey on radiation dose in CT in The Netherlands. Insights Imaging. 2013 Jun;4(3):383–90.

14. Waste, R. (2006). IAEA (International Atomic Energy Agency's) Safety Standards.

15. Kalra MK, Maher MM, Toth TL, Hamberg LM, Blake MA, Shepard JA, et al. Strategies for CT Radiation Dose Optimization. Radiology.